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Sky Quality Meter cross-calibration for the NixNox project

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Abstract

Twelve SQM-L night sky photometers have been calibrated to determine their internal precision and differences in response. Amateur astronomers around Spain, under the supervision of the Spanish Astronomical Society (SEA, Sociedad Española de Astronomía), will use these photometers to locate and characterize sites with dark skies well suited to perform astronomical observations (NixNox Project). A simple experimental setup has been built to obtain zero offsets for each photometer in order to correct all the observations.

1. Introduction

The NixNox Project, proposed and supported by the Spanish Astronomical Society (SEA, for Sociedad Española de Astronomía in Spanish), was created in order to locate places in Spain where enjoying a dark sky at night is still possible in spite of light pollution. The further development of the project wants as many as possible associations of amateur astronomers to get involved in collecting the data. The main objective of the NixNox Project is to encourage people to go out and watch the starry night, to show the amazing sight we could enjoy and teach society how to protect the vision of universe as part of environment.

In later states of the project a unique database will be created, storing the measurements collected by different observers. This is why a previous study of the SQM response is vital to eliminate any dependence on a particular photometer and to allow direct comparison between data. Knowing their internal precision and differences in zero point, the collected values of night sky brightness could be transformed into a common reference frame.

In this report we describe the cross-calibration test that we have performed and we present the results. This work is a continuation of the trainee project of Víctor Muñoz (LICA report 01. December 2010).

Twelve SQM-L photometers were acquired in November 2010 for the NixNox Project (http://www.sea-astronomia.es/drupal/nixnox) by the Spanish Astronomical Society. We have used also two photometers that can be connected to a laptop, models SQM-LE and SQM-LU, for continual measurements that are being used for scientific purposes at the astronomical observatory of the Universidad Complutense

(Observatorio UCM). A number were assigned to each SQM-L photometer, as they are all the same, in order to identify each one of them.

SQM-L Label and Serial Number			
SEA #01 _2.175698	SEA #04 _2.175697	SEA #07 _2.175710	SEA #10 _2.175693
SEA #02 _2.175705	SEA #05 _2.175695	SEA #08 _2.175699	SEA #11 _2.175690
SEA #03 _2.175714	SEA #06 _2.175691	SEA #09 _2.175692	SEA #12 _2.175708

Table 1: Photometer identification by their serial number and the assigned label.

In the previous study by Zamorano & Muñoz (2010) mentioned above, a test for the response of the photometers to daily use was made. They concluded that stable low dispersion measurements under the same light conditions could be achieved only after some days, i.e. a higher random scatter is observed when the SQM-L is used after some days of rest. Data are internally corrected by the effect of temperature on electronics and the user has no access to non-corrected measurements. A change in temperature could introduce some scattering under the same light conditions. But the main result of their study was that some kind of thermalization process takes place by exposing the units to consecutive measurements. After this series of measurements the SQM-L units reach the internal precision of around 0.1 mag/arcsec^2, as the manufacturer states (http://www.unihedron.com). Differences in zero point between units below ~0.1 mag/arcsec^2 were found.

Starting from this point, the objectives of this new study were to calculate zero point differences or offset values for each photometer taking SEA#01 as the master one and to design the instructions to follow by the NixNox observers, when the SQM-L units are delivered among amateur astronomers associations.

2. Design of the test and instrumental setup

To repeat and extend the laboratory tests performed by Zamorano & Muñoz (2010), the same instrumental setup has been used. We chose a blue LED as the light source fed by a stable power supply. The LED is assembled into a black cardboard box, easily homemade, where all measurements will be taken. The SQM-L is placed at the opposite side of the box, whose design assures that the photometers are always held in the same position and orientation. As everything fit exactly in its place in the light sealed box, we are quite sure that no other additional light source influences the experiment. Between the LED and the photometer we include a yellow filter and a diffuser that makes illumination uniform before reaching the SQM unit.

Figure 1-4. : Laboratory experimental setup consisting in a stable power supply and a black box where the blue LED and the yellow filter are placed.

It was mandatory that the photometers were tested in the same conditions. This is why the box has been built with the design and size that ensures that the distance and orientation to the diffuser are always the same.

Not just the laboratory conditions were of interest for this calibration but rather the real ones during an ordinary measurement. This is why we prepare an outdoor experiment to be performed at Observatorio UCM on the terrace of *Facultad de Ciencias Físicas* building. Taking into account that the sky conditions during a night can change relatively quick, we designed an observational setup for field measurements that allow us to acquire a complete set of data as fast as possible, always in the same position and keeping the photometer perfectly vertical, pointing to the zenith. In order to sort this out, we built a zero-budget platform in wood that could be coupled to a tripod.

It is possible to see in figures 5-8 how the SQM-L units are fixed close to the edge while a laptop enabled SQM-LU model is placed in the center. Every single photometer can be manipulated by just turning the merry-go-round platform. An electronic level was used to guarantee the platform is horizontal and every single photometer is pointing to the zenith point. Maximum care was taken when pressing the buttons of the SQMs to assure that the change in inclination of the platform, that has to be revolved between measurements, was kept to a minimum. When the platform is not completely leveled a periodical effect, which could be easily removed, is introduced by the fact of variation in the pointing of the photometers.

Figures 5-8: Platform and tripod for outdoor experiments similar to real field measurements.

3. Testing methods

One of the photometers has to be taken as the master, so the offset of the others will be referred to this master SQM-L, whose offset will be, thus, zero. For the laboratory experiments four groups are organized, always including the master unit.

The blue LED is fed with 5V and 3mA in all laboratory cases, so we registered values around 16.5 mag/arcsec. That illumination level is intentionally higher than typical dark skies in order to check thermalization processes. All photometers were kept in the laboratory during the weeks these experiments were performed, so there was no great change in temperature while they were stored or they were in used.

Group used for test series				
Group	SQM			
1	#01	#02	#03	#04
2	#01	#05	#06	#07
3	#01	#08	#09	#10
4	#01	#11	#12	

We took several series of measurements, usually getting 20 measurements for each photometer. SEA#01, the master photometer, was included in all groups. For this initial test, we wished to calculate the offset making the SQM units work in similar conditions to those while studying dark skies quality. This is why the photometers were not exposed to daily use but leaving one or two days between a series and the next one. Series of data are acquired by groups, we registered a couple of consecutive measurements with every photometer in the group, i.e. we exposed SEA#01 twice, then #02 followed by #03 and finally #04 and we repeated that process ten or fifteen times to complete a series for the first group.

It was found that differences between the first and the second measurement were greater than expected at the beginning of the series. For this reason, we took some other series, the ones we call thermalization series, just taking a lot of consecutive measurements with the same photometer. Both the LED and the room ordinary lamp were used as the light source. But finally, results obtained with the lamp, just two series of 20 measurements, were in great disagreement with the rest of experiments and we decided to exclude them.

Outdoor, SQM units were tested as a first try with the revolving platform mentioned above. We took 7 series of two or three measurements for each photometer. Platform was horizontal for the first series and then we pointed the photometer to six different azimuths at 15 degrees of zenithal distance. The lesson that we learned is that the standard deviation of this data set, taken in the less controlled conditions of the real world outside the laboratory, was greater that those derived from laboratory, as we expected.

The final test of the SQM-L response took place on February 28th 2011 in the terrace on top of the *Facultad de Ciencias Físicas de la Universidad Complutense* building, next to *Observatorio Astronómico UCM*, with the great help of a group of volunteers of *Asociación de Astrónomos Aficionados* (ASAAF-UCM). During the measurements SQM-L units should be placed in one of the spots we previously marked on the sill with a running number. In the middle of these spots we placed the SQM-LE connected to a laptop and registering data during all the experience.

The photometers were distributed among the volunteers, who started the series with first photometer at the first spot and so on. Right after every couple of measurements the volunteers moved with their assigned photometer to the next spot for the next measurement. We collected three series of 24 measurements for each SQM-L unit. All the volunteers read simultaneously the sky brightness so we know exactly what time a certain data was acquired for further comparison with SQM-LE reading. Analyzing the data acquired we concluded that using different positions to measure did not introduce an additional dispersion.

More than 140 other series were taken in addition, while the SQM-LU was reading continuously. To minimize the time a series last, measurements were recorded with a voice recorder instead of written down. It has the advantage that both hands can now be used to manipulate the platform and carry on a more controlled experiment.

Figure 9: Volunteers right after the NixNox public event on February 28th 2011.

4. Results

From the first series of measurements acquired in the laboratory, we checked that SEA#01 photometer shows the most stable behavior. Most of the others present random scatter that exceed the stated internal precision.

We also tested the effect of exposing the photometers to a bright light source before using it to real measurements. Photometers #01 and #12 were exposed to a lamp and stored again immediately after the first series. We can see how better results are shown in the second series, but probably following the general improvement registered for all SQM-L units (see Table 2). Photometers #10 and #8 were exposed to the lamp right after registering Series L2 and then stored again until the following day. No scatter reduction is observed in this case, but they present a worse behavior. Thus, the thermal process we want to achieve by exposing SQM-L units to a lamp does not last in time.

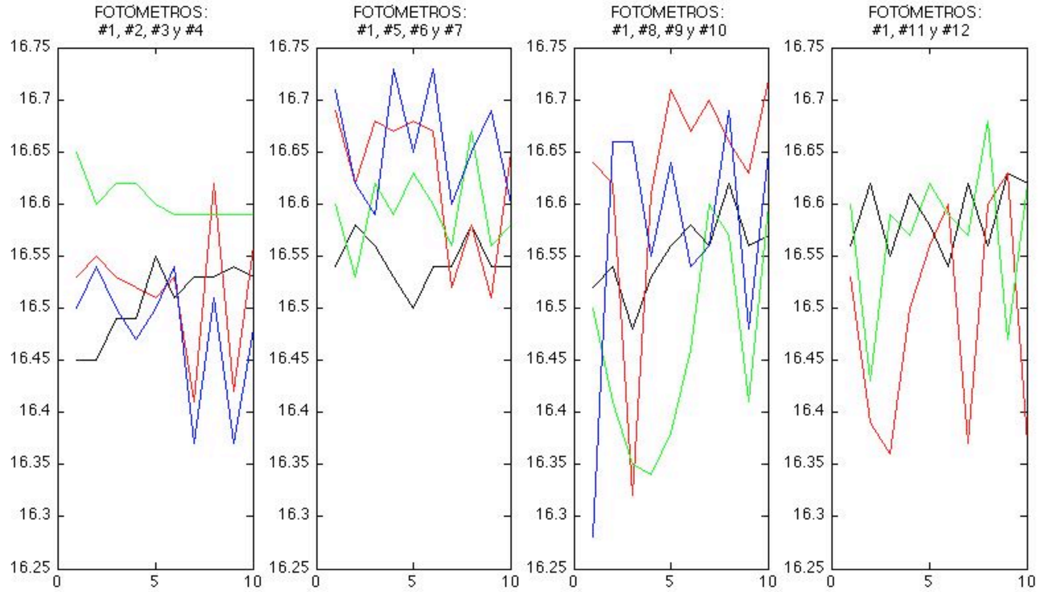


Figure 10: First series of measurements in laboratory. Master SQM-L unit is always the black line. The rest of the photometers in the group are represented, in order of numeration, by the red, green and blue lines.

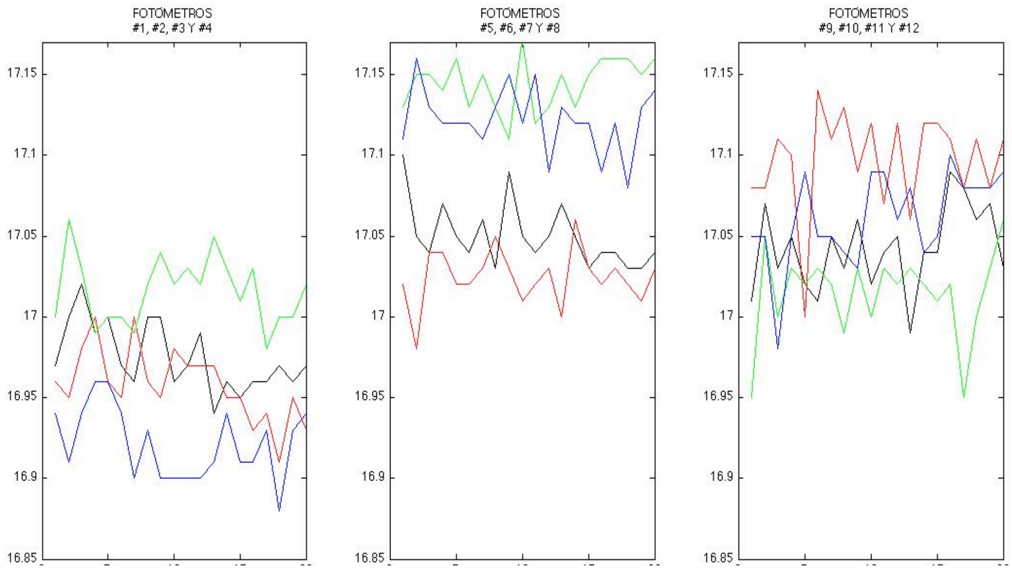


Figure 11: Thermalization series T1 of measurements in laboratory. Black, red, green and blue lines are associated to photometers in the group by order of numeration.

Next series was taking after Christmas time, so photometers had a couple of weeks rest. Photometers #4 and #6 were irradiated just before taking Series L4. We expected to see significant decrease of their dispersions, but that reaction was not observed, but the opposite. At most we can say the exposition to a stronger light source limits the scattering shown while registering a series of measurements using a weaker light source like our LED. Concerning to this subject, taking the especial series with 20 consecutive reading by each photometer resulted much more efficient. We will come back on this subject later, when we give some instructions for acquiring real sky-brightness data.

General improvements in measurements are visible from the very first moment; we observe that the random scattering decreases for all series after using the photometers for a while. With their use, oscillations get smoother and a general trend is easily observed from the first measurements.

On the other hand, we also observe that sometimes an average of two data in a twenty measurements series strongly disagree with that general trend. They are usually brighter than the rest of data, therefore, as the magnitudes are referred to an inverse logarithmic scale, a lower value is registered, but we do not mean greater values cannot be observed.

For example, we registered the following data set for photometer #04 in the Laboratory Series 08:

17.66 – 17.67 – 17.71 – 17.70 – 17.69 – 17.69 – ***17.42*** – 17.71 – 17.71 – 17.65
17.70 – 17.69 – 17.68 – 17.66 – 17.69 – 17.68 – 17.68 – 17.66 – 17.71 – 17.67

Series													
SQM	L1	T1	L2	L3	L4	L5	T2	L6	T3	L7	T4	L8	T5
#01	0.10	0.08	0.09	0.24	0.25	0.09	0.11	0.10	0.09	0.26	0.08	0.13	0.04
#02	0.21	0.09	0.15	0.30	0.26	0.06	0.02	0.09	0.03	0.18	0.12	0.10	0.09
#03	0.06	0.08	1.97	0.52	0.32	0.13	0.55	0.04	0.03	0.09	0.18	0.18	0.07
#04	0.17	0.08	0.21	0.33	0.59	0.12	0.01	0.11	0.03	0.14	0.06	0.29	0.06
#01	0.08	-	0.12	0.11	0.23	0.04	-	0.06	-	0.22	-	0.08	-
#05	0.18	0.07	0.11	0.64	0.67	0.20	0.05	0.06	0.15	0.20	0.03	0.31	0.09
#06	0.14	0.08	0.11	0.24	0.65	0.07	0.02	0.09	0.02	0.18	0.11	0.13	0.08
#07	0.14	0.06	0.10	0.24	0.51	0.41	0.02	0.16	0.03	0.47	0.05	0.30	0.07
#01	0.14	-	0.09	0.37	0.48	0.09	-	0.04	-	0.27	-	0.09	-
#08	0.40	0.08	0.24	0.77	0.23	0.09	0.01	0.06	0.01	0.32	0.10	0.10	0.07
#09	0.25	0.10	0.11	0.48	0.46	0.13	0.00	0.23	0.01	0.34	0.03	0.30	0.11
#10	0.41	0.14	0.20	0.56	1.06	0.12	0.02	0.04	0.01	0.25	0.04	0.15	0.08
#01	0.09	-	0.09	0.38	0.21	029	-	0.24	-	0.32	-	0.11	-
#11	0.27	0.11	0.09	0.59	1.06	0.28	0.11	0.11	0.01	0.32	0.11	0.14	0.12
#12	0.25	0.12	0.19	1.28	0.69	0.23	0.16	0.06	0.03	0.30	0.08	0.10	0.07

Table 2: Difference between the maximum and the minimum value for each SQM-L unit and series. Series T are the thermalization ones, whose data set were acquired by 20 consecutive measurements. Series L are ordinary series acquired in laboratory experiments, as it was explained.

Series													
SQM	L1	T1	L2	L3	L4	L5	T2	L6	T3	L7	T4	L8	T5
#01	0.09	0.05	0.05	0.12	0.09	0.04	0.08	0.06	0.08	0.12	0.06	0.04	0.04
#02	0.15	0.07	0.12	0.11	0.16	0.05	0.02	0.05	0.03	0.13	0.09	0.08	0.07
#03	0.03	0.06	0.07	0.17	0.12	0.06	0.00	0.04	0.03	0.05	0.05	0.08	0.06
#04	0.07	0.06	0.17	0.18	0.09	0.09	0.01	0.08	0.03	0.06	0.04	0.05	0.03
#01	0.08	-	0.09	0.10	0.09	0.03	-	0.05	-	0.16	-	0.04	-
#05	0.16	0.06	0.09	0.21	0.17	0.05	0.04	0.04	0.12	0.16	0.03	0.05	0.08
#06	0.11	0.06	0.09	0.15	0.12	0.05	0.02	0.06	0.02	0.13	0.06	0.06	0.07
#07	0.13	0.05	0.06	0.18	0.12	0.11	0.02	0.06	0.03	0.18	0.05	0.11	0.04
#01	0.10	-	0.07	0.16	0.13	0.06	-	0.04	-	0.08	-	0.06	-
#08	0.11	0.06	0.09	0.21	0.10	0.06	0.01	0.04	0.01	0.23	0.03	0.08	0.05
#09	0.22	0.07	0.06	0.34	0.13	0.07	0.00	0.11	0.01	0.20	0.03	0.10	0.10
#10	0.15	0.07	0.09	0.13	0.20	0.08	0.02	0.04	0.01	0.20	0.04	0.08	0.04
#01	0.08	-	0.05	0.13	0.13	0.06	-	0.06	-	0.24	-	0.08	-
#11	0.26	0.08	0.08	0.12	0.14	0.12	0.08	0.07	0.01	0.28	0.03	0.12	0.08
#12	0.21	0.06	0.14	0.07	0.19	0.11	0.13	0.05	0.03	0.25	0.04	0.08	0.05

Table 3: Difference between the maximum and the minimum value for each SQM-L unit and series, but after eliminating the most dissonant value every ten measurements.

The series in Table 2 and Table 3 have been chronological ordered. As long as we take more and more data the range in values seems to increase due to the effect described above of the spurious values that appear in the series. For example, the largest intervals between the maximum and the minimum measurements correspond to the longest series, L4, with 30 measurements. However, a lower dispersion is observed with common use; in fact, the standard deviation does actually decrease. In order to sort this question out we have eliminated the most incompatible value every ten measurements. Doing so, we obtained an average range a bit slower that internal precision (0.09 ± 0.05). We consider our series in the laboratory as a very well controlled experiment, even though we can see several series with intervals larger than the internal precision as L1, L3, L4 and L7. Those results were not quite unexpected as we stated a low dispersion is observed after routine use.

Offset values were calculated as the difference between a certain photometer's mean value and the master's. So we have an offset value for each series. A final offset is obtained by averaging out offsets for all series weighted with their standard deviations. The same calculations were made using the median, instead of the mean, but the same results were obtained.

When acquiring data from the night sky, it would be wrong to estimate the offset by the difference of the average value of a long series for a particular photometer because light conditions are influenced by many artificial sources and changes in illumination can be very quick. Instead, we will call a collection of one measurement for each photometer, i.e. a complete tour of the platform, a series. So, as a series can be taken in a short elapse of time, we will proceed like this: we will first calculate the average of a series, then calculate an offset relative to this mean value and finally estimate the offset referred to the master photometer by subtracting the master's offset. Up to 175 series were obtained with this method, most of them include a continuous reading with a photometer SQM-LU.

Dispersion is always different for each series so the final offset is calculated using a weighted mean. Errors are estimated as statistical standard deviation from the mean value and it is found that errors are sometimes larger than the offset we are looking for. It must not be forgotten that a precision of 0.1 mag/arcsec^2 is given by the manufacturer and we are working in an order of magnitude lower, i.e. a particular offset calculated for SEA#04 is 0.01 but the precision we can ensure is ten times greater.

We present some plots and tables to illustrate the results we have obtained.

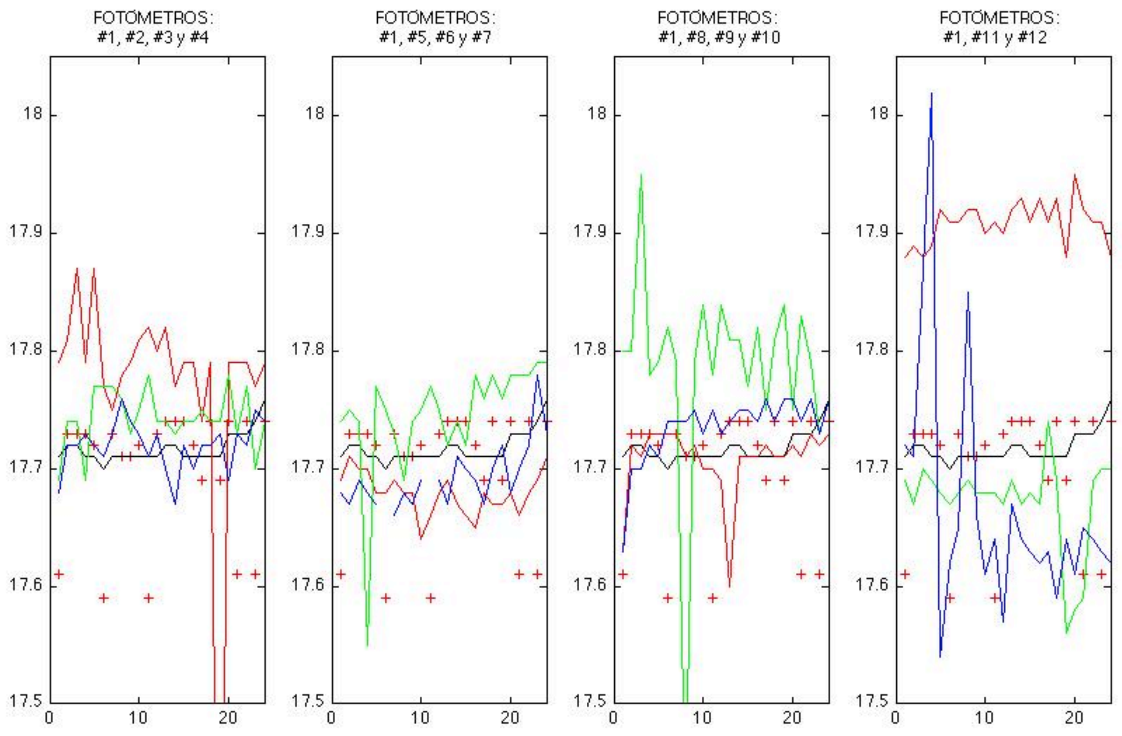
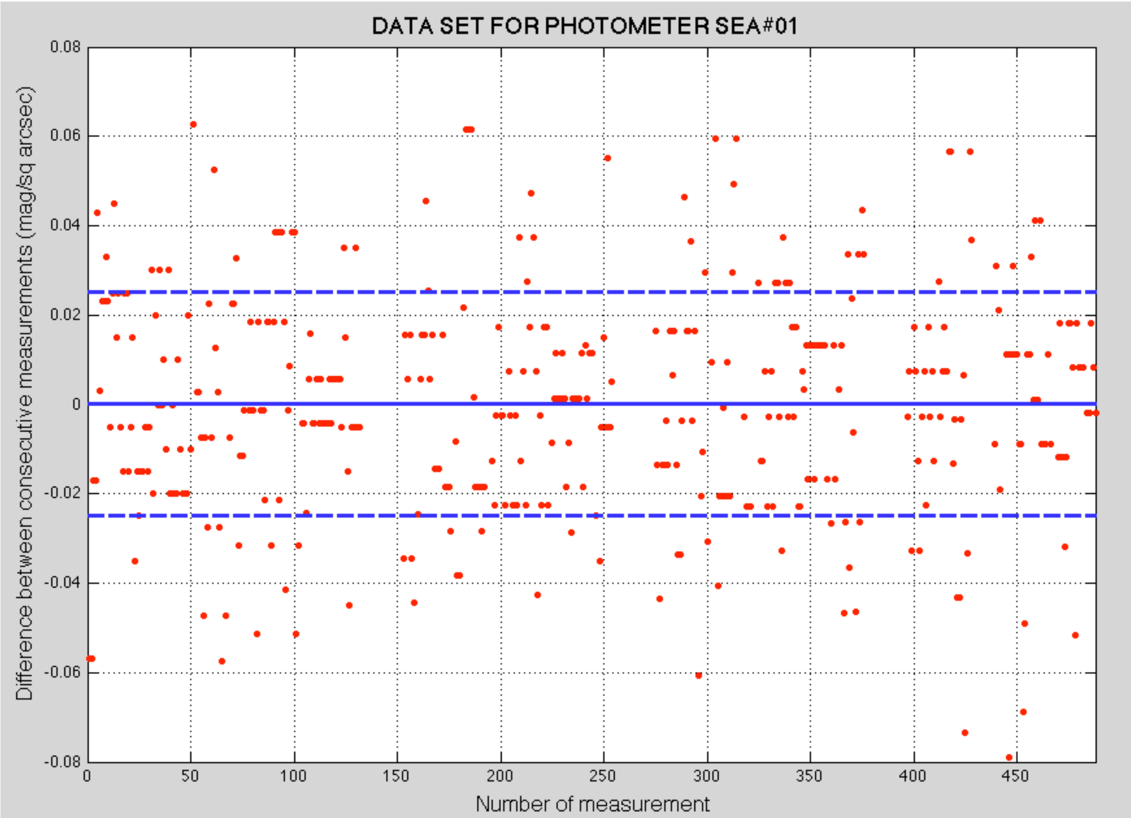
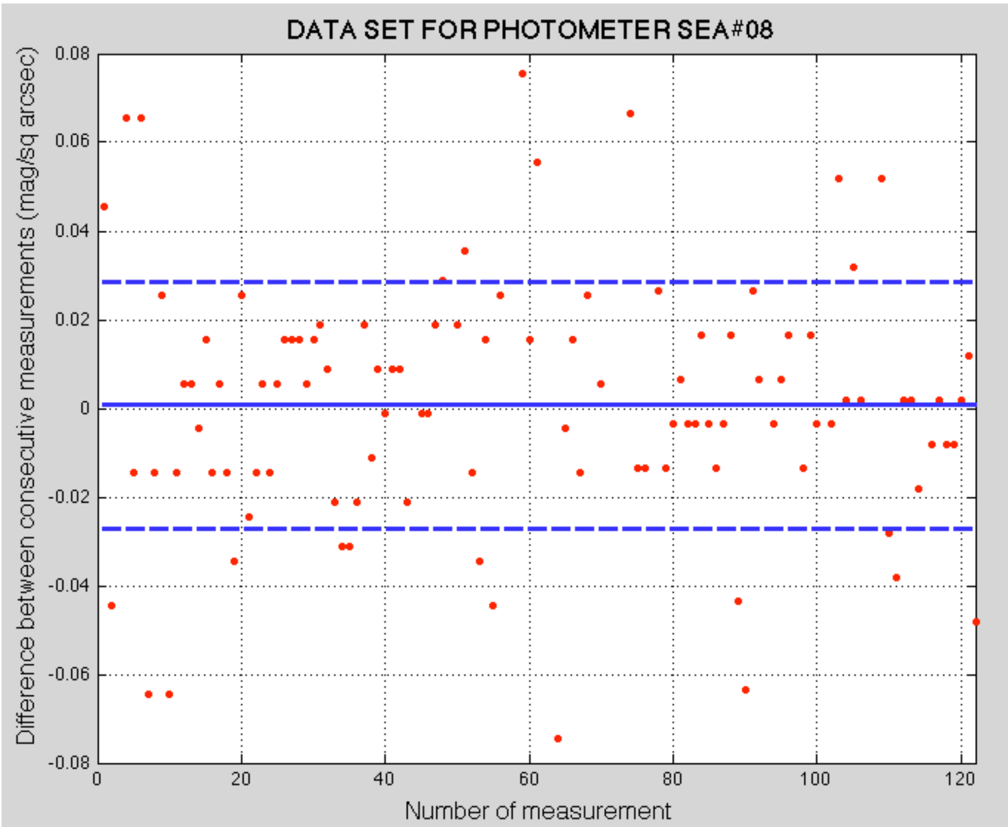


Figure 12: One of the experiences performed thanks to the help of volunteers. A black line always represents SQM SEA #01. Measurements for the rest of units are represented by lines according to their running number: red, green and blue. SQM-LE entries are represented by red crosses, pointing out that the variability range is about 0.10 mag.





Figures 13 and 14: Differences between individual measurements and their average value for SQM-L units SEA#01 and SEA#08, respectively. The mean value, of course practically zero, and the standard deviations are shown in blue lines.

TABLE 3				
N	SQM-L unit			
	#01	#02	#03	#04
1	17.00	16.94	17.02	17.01
2	17.04	16.98	17.02	16.98
3	16.94	16.93	17.00	16.84
4	16.94	16.94	16.99	16.86
5	16.93	16.92	17.02	16.86
6	16.89	16.99	17.02	16.86
7	16.93	16.95	17.03	16.87
8	16.91	16.94	16.99	16.88
9	16.96	17.01	16.98	17.01
10	16.93	17.00	17.10	17.02
11	16.99	17.00	17.04	16.94
12	16.95	17.02	16.97	16.90
13	16.94	16.97	16,87	16.88
14	16.91	17.02	17.05	16.88
15	16.88	16.73	16.58	16.90
16	16.85	17.03	17.01	16.87
17	16.89	17.00	16.98	16.97
18	16.80	17.00	17.06	16.96
19	16.93	16.84	17.03	16.69
20	16.96	17.02	16.93	16.88
21	16.96			
22	16.97			

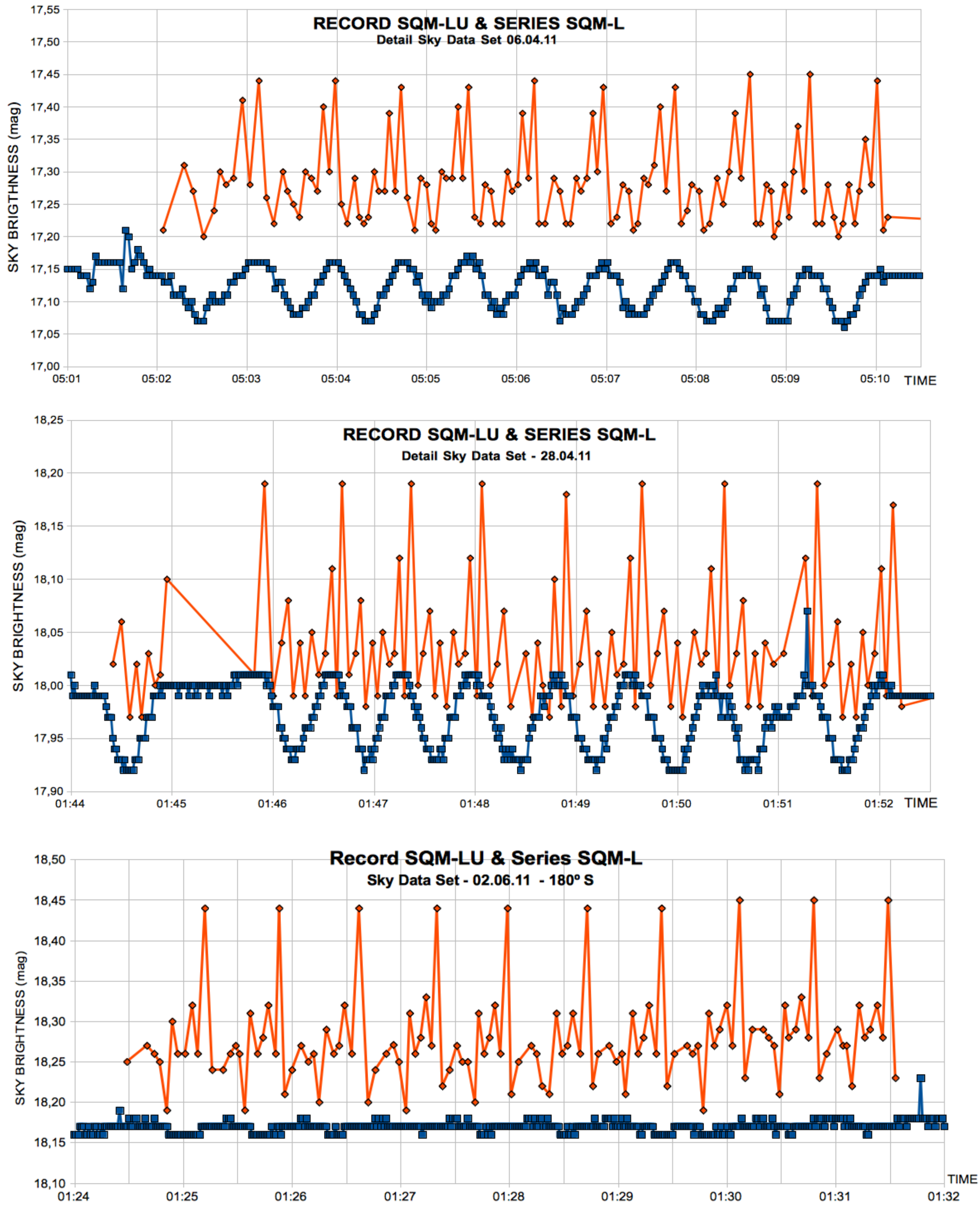
TABLE 4 (all data)				
Statistics	#01	#02	#03	#04
Maximum	17.04	17.03	17.10	17.02
Minimum	16.80	16.73	16.58	16.69
Range	0.24	0.30	0.52	0.30
No. of data	22	20	20	20
Mean	16.93	16.96	16.98	16.90
Median	16.94	16.99	17.02	16.88
RMS	0.05	0.07	0.10	0.07
Offset	-	0.03 ± 0.09	0.05 ± 0.12	-0.03 ± 0.09

TABLE 5 (without outliers)				
Statistics	#01	#02	#03	#04
Maximum	17.00	17.03	17.10	17.01
Minimum	16.88	16.92	16.93	16.84
Range	0.12	0.11	0.17	0.17
No. of data	19	18	18	18
Mean	16.94	16.98	17.01	16.91
Median	16.94	17.00	17.02	16.88
RMS	0.03	0.03	0.04	0.05
Offset	-	0.04 ± 0.05	0.08 ± 0.05	-0.03 ± 0.06

Table 3: Data set for a typical laboratory series. The values in red were discarded for further analysis.

Table 4: Statistical values for a typical series. We can see how some dissonant measurements appear and how standard deviation for offsets is usually higher than them.

Table 5: Statistical values for a typical series without outliers. Range and standard deviation decrease considerably. Offsets still have error bars of its order of magnitude.



Figures 15 - 17: Detail of some series of data acquired from the night sky. SQM-LU readings are represented in blue and the whole series acquired with the SQM-L are represented in orange. Note the periodical effect of turning the platform. This effect was minimum in the experience performed in June 2nd, although much attention was paid in manipulation.

We observe that, despite of the care we took on the positions and orientation of photometer on the platform, a certain shift is introduced while manipulating. The main effect is due to the fact that the platform in not completely leveled. The last example is the most controlled experiment at this respect, where the variation in the SQM-LU reading is less than 0.04 mag/arcsec^2, although the perfect leveling disappeared after several series. It is interesting to note that a deviation of 1 degree in leveling yields differences of 0.07 mag/arcsec^2 for an urban area. This effect, however, should work in the same way for all SQM-L units as they are placed always in the same positions while measuring.

In resume, we have acquired a complete data set under different conditions. We have paid great attention to every detail while manipulating the photometers, as we have pointed out in the description of the experiments. However we find slightly different results, i.e. offset values calculation that was our main objective, when taking different subsets of data. Those differences are independent of the level of illumination. Repeating exactly the same calibration experience is a very hard target.

We finally present our results in the following table with the adopted offset:

SQM-L	Laboratory	Night Sky	OFFSET
#02	0.01 ± 0.06	0.08 ± 0.01	**0.07 ± 0.01**
#03	0.07 ± 0.05	0.02 ± 0.02	**0.03 ± 0.01**
#04	-0.01 ± 0.05	-0.02 ± 0.03	**-0.02 ± 0.01**
#05	0.06 ± 0.08	-0.02 ± 0.01	**-0.01 ± 0.01**
#06	0.04 ± 0.04	0.03 ± 0.01	**0.04 ± 0.01**
#07	0.11 ± 0.06	0.00 ± 0.02	**0.02 ± 0.01**
#08	0.10 ± 0.05	0.01 ± 0.02	**0.03 ± 0.01**
#09	0.02 ± 0.06	0.09 ± 0.01	**0.08 ± 0.01**
#10	0.05 ± 0.05	0.02 ± 0.02	**0.02 ± 0.01**
#11	0.06 ± 0.08	0.14 ± 0.05	**0.12 ± 0.01**
#12	0.01 ± 0.05	-0.02 ± 0.02	**-0.02 ± 0.01**

Table 6: Offset calculated as the weighted mean for results of all laboratory series (about 450 measurements) and all night sky series (about 250 measurements). A final offset is also shown in the last column.

5. Additional test with AstMon-UCM

We have performed additional tests in different nights to find whether we can obtain the mean value of the night sky brightness at Observatorio UCM. The Astronomical Monitor of Observatorio UCM (AstMon-UCM) could be used for comparison purposes.

Although top-quality conditions were desired, non-ideal weather conditions or light pollution had some influence during the process. An example of how harmful bad weather conditions can be is represented in Figure 19. Due to this fact, it is very hard to decide a precise sky brightness value for UCM Observatory. In the following table values for different experiences can be found:

Date	Start (Local Time)	Stop (Local Time)	**Sky Brightness (SQM-L)**
Feb 28th 2011	19:53	20:09	17.61 ± 0.08
Feb 28th 2011	20:23	20:34	17.68 ± 0.05
Feb 28th 2011	20:51	21:03	17.71 ± 0.05
April 6th 2011	05:02	05:44	17.23 ± 0.04
April 28th 2011	01:44	02:02	18.00 ± 0.03
June 2nd 2011	01:24	03:01	18.24 ± 0.04

Table 7: Sky Brightness characterization for Observatorio UCM, from experiments with SQM-L. All measurements of hand held SQM-L units have been corrected from adopted offset, as gathered in table 6.

As we obtained very low dispersion, the straightforward conclusion is that different sky brightness conditions were observed in different occasions. Bias offset calculations have been widely discussed for SQM-L units. We can now obtain similar results related to automatic SQM units we used during the experiments and ASTMON.

- For our Ethernet-enabled SQM-LE unit, whose serial number is 00000845, entries are (0,04 ± 0,01) below the average of measurements for a SQM-L series. As figure 18 shows, this behavior remains very stable until a connection error happened, causing the lack of registration in part of the experiment. When the experimental assembly was restored a different and more scattered data set was acquired.

- For the USB-enabled SQM-LU unit, whose serial number is 00001738, we obtained separate trends depending on the experiment. Manipulation is not completely harmless; a particular patron can be distinguished in dataset (see Figures 20, 21, and 22) due to the hand-made roulette. Despite this fact, we extract the following values, trusting especially in the last one, as the manipulation patron appears reduced in that experiment: 06 April 2011 - (0,10 ± 0,05); 28 April 2011– (0,03 ± 0,04) and 02 June – (0,09 ± 0,03).

- Available data for ASTMON might not be enough to be significant. However, a very stable behavior is observed and so, some results can be obtained at least as a first approach. It should be noted that AstMon values presented here correspond to Johnson V band. SQM band covers both B and V Jonson bands. The difference between SQM magnitude and V magnitude depends on the color of the sky that is related to the light pollution. Other test performed at Observatorio UCM shows a difference of SQM-V ≈ 0.2 and B-SQM ≈ 0.4 magnitudes.

AstMon fisheye uses a zenithal projection for which every pixel subtends a certain solid angle, being 133px the equivalent field of view to the half width half maximum of the angular sensitivity for SQM-L units, i.e. 10 degrees. AstMon magnitudes in both bands were produced using the free-license fits files editor fv, provided by NASA. With this software we created a circle region taking a 133px radius from the centroid of the image (1224px, 1239px). A mean value with standard deviation is automatically calculated. Although we trust in the specifications provided by the SQM-L manufacturer, we have tried different radius from 100px (7.5 degrees) to 330px (12.5 degrees) just to check the importance of a precise field of view determination, finding differences around 0.005 mag within 200px and no greater than 0,06 mag when comparing the 100px with 330px. We give the results for AstMon in the following table:

Date	Time	Band B (± 0.01 mag)	Time	Band V (±0.0003 mag)
28-feb-2011	20:49:26	18.22	20:50:19	17.33
28-feb-2011	20:58:41	18.3	20:59:32	17.39
28-feb-2011	21:07:53	18.34	21:08:44	17.4
28-apr-2011	01:43:54	19.21	01:44:51	17.76
28-apr-2011	01:50:05	19.21	01:51:03	17.76
28-apr-2011	01:56:18	19.21	01:57:15	17.76
28-apr-2011	02:02:30	19.23	02:03:27	17.76
01-jun-2011	01:34:55	19.23	01:35:28	17.87
01-jun-2011	01:40:55	19.25	01:41:57	17.89
01-jun-2011	01:47:25	19.23	01:48:28	17.91
01-jun-2011	01:53:55	19.25	01:54:59	17.91
01-jun-2011	02:00:25	19.25	02:01:28	17.94
01-jun-2011	02:06:56	19.28	02:07:59	17.96
01-jun-2011	02:13:26	19.29	02:14:28	17.97
01-jun-2011	02:19:55	19.29	02:20:59	17.96
01-jun-2011	02:26:26	19.29	02:27:29	17.96
01-jun-2011	02:32:57	19.29	02:34:00	17.96
01-jun-2011	02:39:30	19.29	02:40:34	17.94
01-jun-2011	02:46:00	19.27	02:47:05	17.92
01-jun-2011	02:52:34	19.28	02:53:37	17.92
01-jun-2011	02:59:05	19.28	03:00:07	17.95

Table 8: Available data set from AstMon during the time SQM experiments were in progress. Error bars for AstMon magnitudes are calculated are standard deviation within the circle region created using fv software.

With those magnitudes we obtained a mean difference, similar to zero offset, between AstMon V and B bands and SQM, i.e. offset-corrected SQM-L measurements and our SQM-LU unit:

	ASTMON	SQM-L vs. ASTMON		SQM-LU vs. ASTMON	
Date	B - V	B	V	B	V
Feb 28th 2011	0.91 ± 0.02	0.58 ± 0.01	0.33 ± 0.01	-	-
April 28th 2011	1.45 ± 0.01	1.18 ± 0.02	0.27 ± 0.02	1.25 ± 0.03	0.20 ± 0.03
June 2nd 2011	1.34 ± 0.01	0.99 ± 0.01	0.35 ± 0.01	1.10 ± 0.04	0.24 ± 0.04

Table 9: Differences between Sky Quality Meter measurements, hand-held SQM-L and automatic USB-enabled SQM-LU, and AstMon.

Even though our data set is very small, we obtain the following numbers for the Observatorio UCM: (SQM-V = 0.32 ± 0.03) and (B-SQM = 1.09 ± 0.09), where the value in band B corresponding to February 28th 2011 has been discarded, since it differs much from those coming the other experiences, probably because it was obtained right after the astronomical sunset and we just got three measurements.

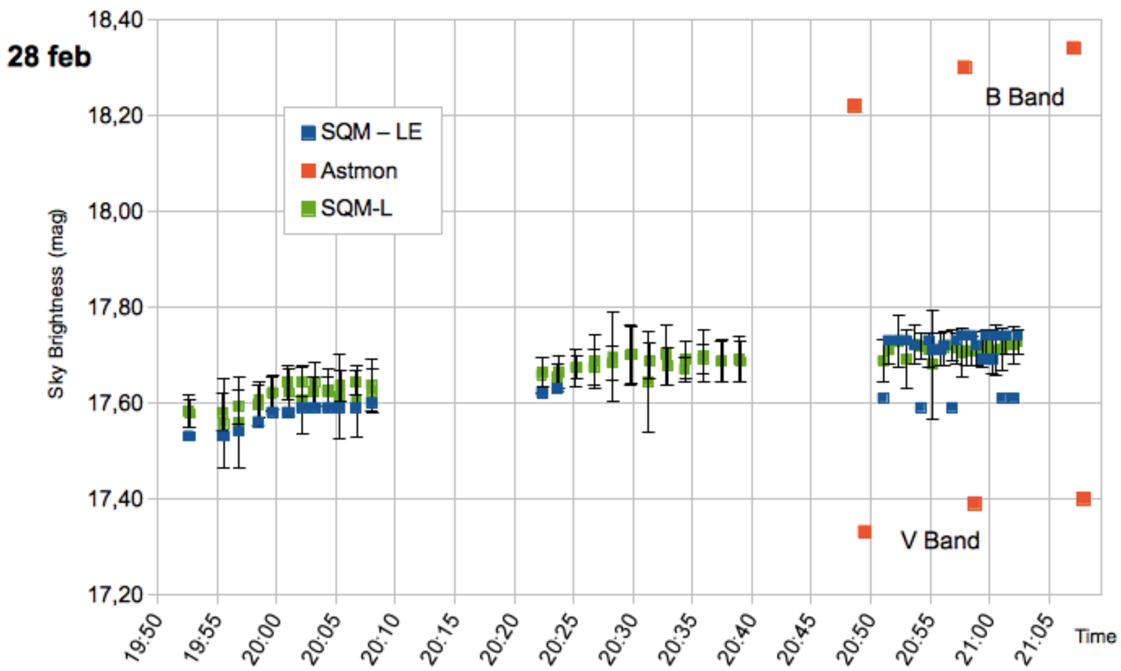


Figure 18: Results of the test we performed on February 28th 2011 on the terrace of the *Facultad de Ciencias Físicas* building thanks to ASAAF volunteers. Hand-held SQM-L measurements are averaged out for all units, after applying the correcting offset. We can see SQM-LE record follows the same trend in general. We represent as well the available data acquired with ASTMON, in both Band V and Band B.

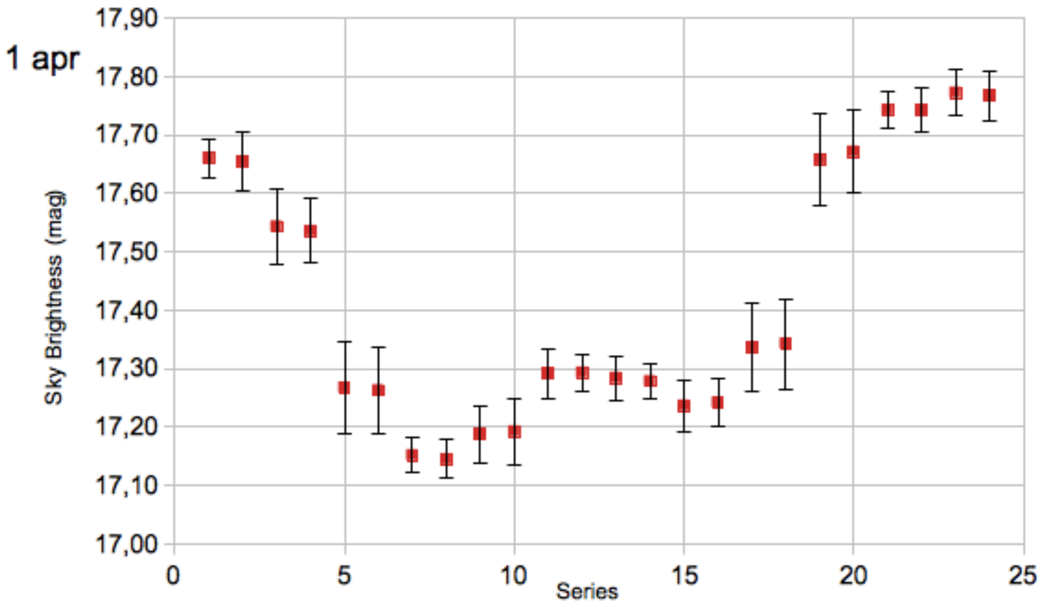


Figure 19: Measurements on a non-voice-recorded experience with SQM-L units. Each point corresponds to an average for a particular series, having corrected measurements from the offset deviation. It shows the high variability observed in non-ideal weather conditions. Time range is about one hour and a half.

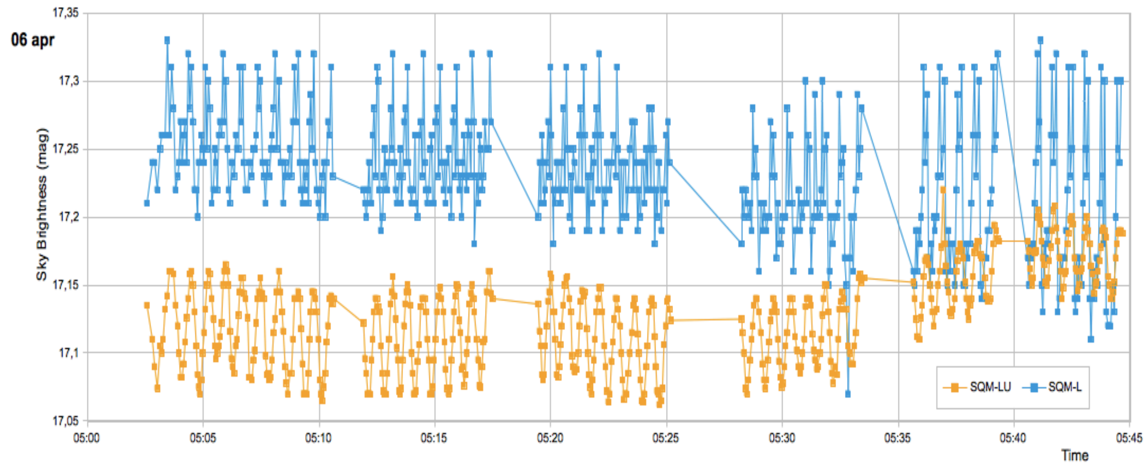


Figure 20: Results of the first experience with the wood roulette coupled to a tripod. Even after having corrected measurements, a particular patron due to manipulation for each series can be distinguished. Especially at the beginning of the experiment, a more or less constant difference between the hand-held and automatic SQM units is registered.

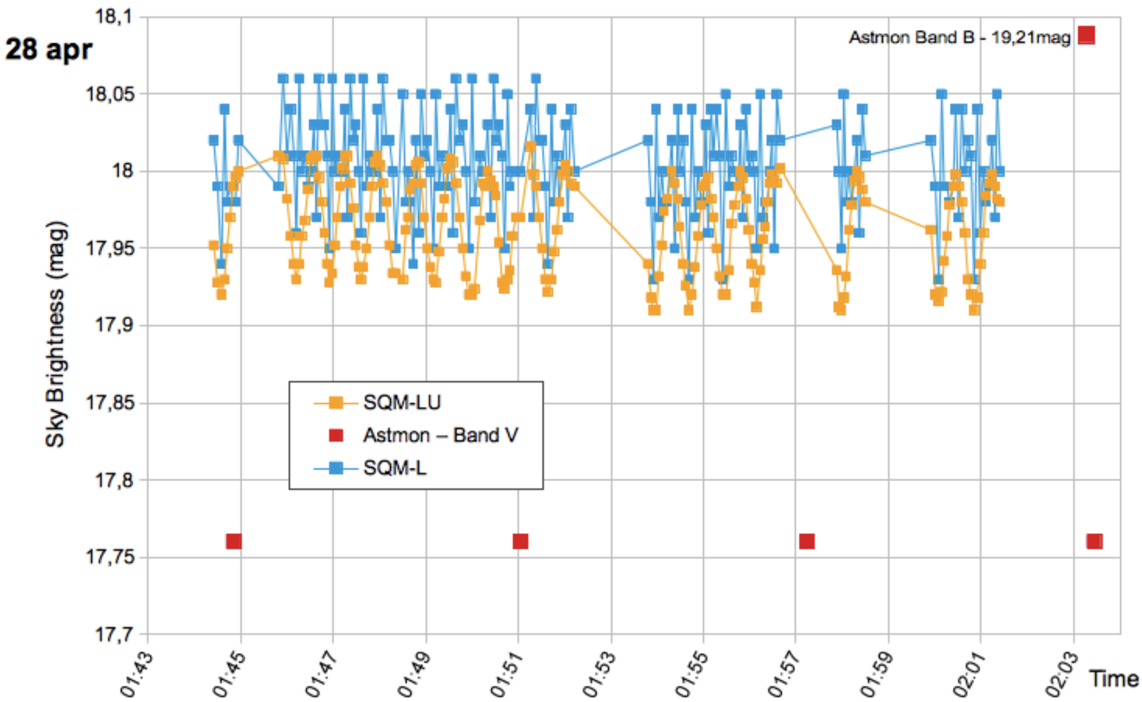


Figure 21: Comparison among corrected measurements acquired with SQM-L units, SQM-LU and AstMon-UCM. The least difference between SQM-L units and SQM-LU is observed, while the manipulation patron could not been removed.

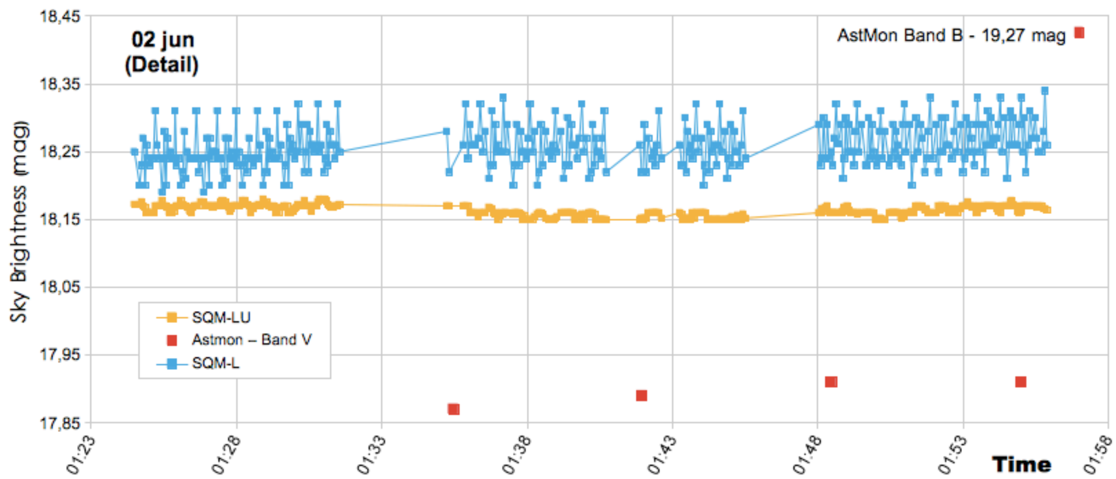


Figure 22: Comparison among corrected measurements acquired with SQM-L units, SQM-LU and AstMon-UCM. SQM-LU measurements are within a narrow range, despite the influence of manipulation.

6. Discussion and conclusion

The offset results obtained at laboratory-controlled conditions and those with test outdoors are consistent, although night sky series have large error bars. Even though offsets obtained under laboratory conditions were expected to be more precise, entries collected right after rest periods raise the standard deviation for the data set; typically around 0.5 compared to ≈0.2 for the night sky experiments.

The observer should be aware of the presence of weird values that appear when taking a series of measurements. We strongly recommend obtaining series of measurements, to write down all the values and to apply later statistical analysis to get rid of these outliers.

We were able to estimate the real precision achieved when measuring in the field using the test with all the SQMs manipulated by different observers, reading simultaneously at the same location. We will adopt a precision of 0.1 for measurements in the field.

The mean value measured for the sky brightness taking into account all experiments with SQM-L units at Observatorio UCM (Madrid urban area) was 17.7 ± 0.5. The great dispersion is due to a significant change in brightness between different nights and also for the variation along the night of the sky brightness expected in a polluted area. A definitive and repeatable characterization for Observatorio UCM may be a hard task, since light pollution and air contamination play a harmful role. A first attempt in comparing AstMon with the SQM at the Observatory UCM is also detailed in this report, having obtained some preliminary numbers.

All the data series obtained outdoors pointing to zenith at night have been very useful to realize how much care should be taken and the things that are important to bear in mind. With that experience we recommend amateur astronomers involved in the NixNox project:

- Observations should be made at night, without the Moon over the horizon.
- Observing during clear nights without clouds is mandatory. Cirrus clouds increase night sky brightness at polluted areas.
- Extract the SQM photometer from its plastic bag a while before starting measurements, so it can achieve the ambient temperature.
- Take some measurements pointing to different places before acquired the real data set. Throw away this data but check that the SQM internal temperature is equal to the ambient temperature.
- It is very important to use a photographic tripod and control the angle and orientation of the SQM unit with any kind of level.
- Avoid any kind of obstacle or light source in the field of view of the SQM (around 20 degrees at half sensitivity). The photometer should be higher than your head.
- Please be aware of possible water vapor condensation on the photometer window. Handle the SQM-L unit with the maximum care to avoid any kind of

damage like bordering its window or getting it dirty.

- Take at least a series of 10 consecutive measurements and write down all of them. To obtain the precision of the measurements, statistics analysis should be performed later.
- Register geographic coordinates with a GPS and annotate the time of the beginning and end of observation in UT.
- The most important value is that corresponding to the zenith. An all sky map of the night sky brightness could be obtained pointing the SQM to 12 azimuths (30 degrees step) at the altitude or elevation of 20, 40, 60 and 80 degrees.

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